FORM PTO-1390 DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE
(REV 5-93)

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NO.
859063.464

U.S. APPLICATION NO. (If known, see 37 CFR 1.5)
Unknown 09/720132

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/FR00/00477	**25 February 2000 (25.02.2000)**	**26 February 1999 (26.02.1999)**

TITLE OF INVENTION
MULTICARRIER SIGNAL RECEIVER WITH CORRECTION OF EQUALIZATION FAULTS INDUCED BY THE TRF WINDOW DISPLACEMENTS

APPLICANT(S) FOR DO/EO/US
MEYER, Jacques

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☐ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☐ is transmitted herewith (required only if not transmitted by the International bureau).
   b. ☒ has been transmitted by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☒ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3)).
   a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ have been transmitted by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☒ have not been made and will not be made.
8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11 to 16 below concern document(s) or information included:

11. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. ☒ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☒ A FIRST preliminary amendment.
    ☐ A SECOND or SUBSEQUENT preliminary amendment.
14. ☐ A substitute specification.
15. ☐ A change of power of attorney and/or address letter.
16. ☒ Other items or information.

    Postcard and check for filing fees.

    Applicant hereby claims priority from **French** Application No. **99/02653** filed **26 February 1999**.

EXPRESS MAIL MAILING LABEL

NUMBER **EL615484377US**

DATE OF DEPOSIT **19 December 2000**

I hereby certify that this paper or fee is being deposited with the United States Postal Service "EXPRESS MAIL POST OFFICE TO ADDRESSEE" service under 37 C F R 1 10 on the date indicated above and is addressed to: Assistant Commissioner for Patents, Washington D C 20231-0001

C. Jeanette Ulust

Signature

JC01 Rec'd PCT/PTO 19 DEC 2000

U.S. APPLICATION NO. (If known, see 37 CFR 1.5)	INTERNATIONAL APPLICATION NO.	ATTORNEY'S DOCKET NUMBER
Unknown 09/720132	PCT/FR00/00477	859063.464

17. ☒ The following fees are submitted:

	CALCULATIONS PTO USE ONLY
Basic National Fee (37 CFR 1.492(a)(1)-(5)):	
Search Report has been prepared by the EPO or JPO ..... $ 860.00	
International preliminary examination fee paid to USPTO (37 CFR 1.482) ..... $ 690.00	
No international preliminary examination fee paid to USPTO (cu CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2)) ..... $ 710.00	
Neither international preliminary examination fee (37 CFR 1.482) nor International search fee (37 CFR 1.445(a)(2)) paid to USPTO $1000.00	
International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) ..... $ 100.00	
ENTER APPROPRIATE BASIC FEE AMOUNT =	$860.00
Surcharge of $130.00 for furnishing the oath or declaration later than ☐ 20 ☒ 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	$.00

Claims	Number Filed	Number Extra	Rate	
Total Claims	17 - 20 =		x $ 18.00	$.00
Independent Claims	3 - 3 =		x $ 80.00	$.00
Multiple dependent claim(s) (if applicable)			+ $270.00	$.00

TOTAL OF ABOVE CALCULATIONS =	$860.00
Reduction by ½ for filing by small entity, if applicable. Verified Small Entity statement must also be filed. (NOTE: 37 CFR 1.9, 1.27, 1.28)	$.00
SUBTOTAL =	$860.00
Processing fee of $130.00 for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(f)). +	$.00
TOTAL NATIONAL FEE =	$.00
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). $40.00 per property) +	$40.00
TOTAL FEES ENCLOSED =	**$900.00**
	Amount to be refunded:
	charged

a. ☒ A check in the amount of $900.00 cover the above fees is enclosed.

b. ☐ Please charge my Deposit Account No. in the amount of $_ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. **19-1090**. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

GASH, Eric, J.
Seed Intellectual Property Law Group PLLC
6300 Columbia Center
701 5th Avenue
Seattle, WA 98104-7092
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SIGNATURE

Eric J. Gash
NAME

46,274
REGISTRATION NUMBER

09/720132

JC01 Rec'd PCT/PTO 19 DEC 2000

PTO/SB/17 (09-00)
Approved for use through 10/31/2002. OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
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FEE TRANSMITTAL for FY 2001

Patent fees are subject to annual revision.

TOTAL AMOUNT OF PAYMENT ($) 2140

Complete If Known	
Application Number	PCT/FR00/00477
Filing Date	25 February 2000
First Named Inventor	MEYER, Jacques
Examiner Name	
Group Art Unit	
Attorney Docket No.	859063.464

METHOD OF PAYMENT

1. ☒ The Commissioner is hereby authorized to charge indicated fees and credit any overpayments to:

Deposit Account Number: 19-1090

Deposit Account Name: Seed Intellectual Property Law Group PLLC

☒ Charge Any Additional Fee Required Under 37 CFR 1.16 and 1.17

☐ Applicant claims small entity status. See 37 CFR 1.27

2. ☒ **Payment Enclosed:**

☒ Check ☐ Credit card ☐ Money Order ☐ Other

FEE CALCULATION

1. BASIC FILING FEE

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
101	710	201	355	Utility filing fee	
106	320	206	160	Design filing fee	
107	490	207	245	Plant filing fee	
108	710	208	355	Reissue filing fee	
114	150	214	75	Provisional filing fee	

SUBTOTAL (1) ($)

2. EXTRA CLAIM FEES

	Extra Claims below		Fee Paid
Total Claims	-20** =	X	=
Independent Claims	- 3** =	X	=
Multiple Dependent			=

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description
103	18	203	9	Claims in excess of 20
102	80	202	40	Independent claims in excess of 3
104	270	204	135	Multiple dependent claim, if not paid
109	80	209	40	** Reissue independent claims over original patent
110	18	210	9	** Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) ($)

**or number previously paid, if greater; For Reissues, see above

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
105	130	205	65	Surcharge - late filing fee or oath	
127	50	227	25	Surcharge - late provisional filing fee or cover sheet	
139	130	139	130	Non-English specification	
147	2,520	147	2,520	For filing a request for *ex parte* reexamination	
112	920*	112	920*	Requesting publication of SIR prior to Examiner action	
113	1,840*	113	1,840*	Requesting publication of SIR after Examiner action	
115	110	215	55	Extension for reply within first month	
116	390	216	195	Extension for reply within second month	
117	890	217	445	Extension for reply within third month	
118	1,390	218	695	Extension for reply within fourth month	
128	1,890	228	945	Extension for reply within fifth month	
119	310	219	155	Notice of Appeal	
120	310	220	155	Filing a brief in support of an appeal	
121	270	221	135	Request for oral hearing	
138	1,510	138	1,510	Petition to institute a public use proceeding	
140	110	240	55	Petition to revive - unavoidable	
141	1,240	241	620	Petition to revive - unintentional	1240
142	1,240	242	620	Utility issue fee (or reissue)	
143	440	243	220	Design issue fee	
144	600	244	300	Plant issue fee	
122	130	122	130	Petitions to the Commissioner	
123	50	123	50	Petitions related to provisional applications	
126	240	126	240	Submission of Information Disclosure Stmt	
581	40	581	40	Recording each patent assignment per property (times number of properties)	40
146	710	246	355	Filing a submission after final rejection (37 CFR § 1.129(a))	
149	710	249	355	For each additional invention to be examined (37 CFR § 1.129(b))	
179	710	279	355	Request for Continued Examination (RCE)	
169	900	169	900	Request for expedited examination of a design application	
Other fee (specify)				PCT Conversion	860

* Reduced by Basic Filing Fee Paid SUBTOTAL (3) ($) 2140

SUBMITTED BY				Complete (if applicable)	
Name (Print/Type)	Eric J. Gash	Registration No. (Attorney/Agent)	46,274	Telephone	(206) 622-4900
Signature				Date	19 Dec 00

WARNING: Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

Burden Hour Statement: This form is estimated to take 0.2 hours to complete. Time will vary depending upon the needs of the individual case. Any comments on the amount of time you are required to complete this form should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, Washington, DC 20231. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Assistant Commissioner for Patents, Washington, DC 20231.

PATENT COOPERATION TREATY

Int'l Application No.	:	PCT/FR00/00477
Int'l Filing Date	:	25 February 2000
U.S. Application No.	:	unknown
Inventor	:	MEYER, Jacques
Title	:	MULTICARRIER SIGNAL RECEIVER WITH CORRECTION OF EQUALIZATION FAULTS INDUCED BY THE TRF WINDOW DISPLACEMENTS
Docket No.	:	859063.464
Date	:	19 December 2000

Box PCT
Assistant Commissioner for Patents
Washington, DC 20231-0001

PRELIMINARY AMENDMENT

Sir:

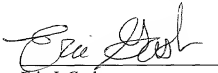
Applicants respectfully request entry of preliminary amendments in the above-identified United States National Phase patent application. Please amend the claims as follows:

In the Claims:

Delete claims 1-3 as originally filed, and substitute therefor attached U.S. claims 1-17.

Respectfully submitted,

Seed Intellectual Property Law Group PLLC



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CLAIMS

What is claimed is:

1. A COFDM demodulator, comprising:

a fast Fourier transform circuit for analyzing a received signal in a window corresponding to one symbol, each symbol carrying several phase and amplitude modulated carriers, some of which, shifted in frequency in a predetermined way from one symbol to the next one, form pilots;

a bidimensional filter for interpolating, from anchors corresponding to the pilots such as received from several consecutive symbols, the distortion undergone by each carrier;

means for correcting window shifting with respect to an optimal position; and

means for correcting each distortion according to window shifting corrections performed respectively for the symbol associated with the distortion and for the symbols associated with the anchors used to interpolate the distortion.

2. The demodulator of claim 1 wherein the means for correcting the window shifting comprise a phase-locked loop synchronized on a correlation signal obtained by a correlation product between the received signal and this same signal delayed by one symbol, each symbol being preceded by a guard interval corresponding to a copy of the end of the symbol.

3. The demodulator of claim 1 wherein each distortion is, in the frequency field after Fourier transform, a weighted sum of two anchors of the same position in a preceding symbol and in a following symbol, to which anchors have been added respective phases corresponding to the shiftings undergone by the analysis window for the preceding and following symbols, and to which anchors has been subtracted a phase corresponding to the shifting undergone by the analysis window for the symbol associated with the distortion.

4. A COFDM demodulator with fast Fourier transform (FFT) analysis window displacement compensation, comprising:

a reconstruction circuit configured to receive radio-transmitted signals in a window corresponding to one symbol, the symbol carrying a plurality phase and amplitude modulated carriers, one or more of the carriers are shifted in frequency in a predetermined way from one symbol to the next symbol and form pilots, the reconstruction circuit configured to extract the symbols and convert the symbols into digital signals;

an adjustment circuit and an associated phase-locked loop (PLL) circuit configured to receive the digital signals and determine and readjust the position of the corresponding windows;

an FFT circuit configured to perform a fast Fourier transform with the windows and output a transformed signal including complex coefficients;

a conversion circuit configured to receive a position signal from the PLL and to output a conversion signal that is corrected for distortion;

a distortion interpolation circuit configured to receive the transformed signal and the conversion signal and to provide an interpolated distortion signal; and

a correction circuit configured to receive the interpolated distortion signal and to output a corrected complex coefficients signal.

5. The demodulator of claim 4, further comprising a delay circuit coupled between the FFT circuit and the correction circuit and coupled in parallel with the distortion interpolation circuit.

6. The demodulator of claim 4 wherein the PLL is configured to be synchronized on a correlation signal obtained by a correlation product between the received radio-transmitted signals in a window and this same signal delayed by one symbol, each symbol being preceded by a guard interval corresponding to a copy of the end of the symbol.

7. The demodulator of claim 4 wherein the PLL comprises an accumulator that outputs the absolute position of the window with respect to a corresponding symbol.

8. The demodulator of claim 7 wherein the conversion circuit is configured to convert the absolute position received from the PLL into a form that is usable by the distortion interpolation circuit.

9. The demodulator of claim 4 wherein the PLL is configured to control the adjustment circuit.

10. The demodulator of claim 4 wherein the interpolation circuit comprises:

first, second, and third anchor input registers coupled to a first multiplexer;

fourth, fifth, and sixth anchor input registers coupled to a second multiplexer; and

first and second multipliers each having inputs coupled respectively to the first and second multiplexers, and each further having an output coupled to a common adder.

11. The demodulator of claim 10 wherein the conversion circuit comprises:

first, second, and third analysis window shift value registers coupled to a first multiplexer;

fourth, fifth, and sixth analysis window shift value registers coupled to a second multiplexer;

the first and second multiplexers each having an output coupled to respective inputs of first and second adders;

the first and second adders each having an output coupled to respective first and second multipliers;

the first and second multipliers each having an output coupled to respective first and second polar-to-cartesian converters; and

the first and second polar-to-cartesian converters each having an output coupled to respective second inputs of the first and second multipliers of the interpolation circuit.

12. The demodulator of claim 11 wherein the first and second multipliers of the interpolation circuit comprise complex multipliers.

13. The demodulator of claim 11 wherein the interpolation circuit is configured to calculate distortion according to the following:

$$d_{n,k} = \left(1 - \frac{s}{4}\right) A_{n-s,k} e^{j2\pi f_k (w_{n-s} - w_n)} + \frac{s}{4} A_{n+4-s,k} e^{j2\pi f_k (w_{n+4-s} - w_n)}$$

where

A is the received anchors,

S is equal to (n modulo 4 - k/3 modulo 4) modulo 4,

n is the symbol number,

k is the window position,

f_k is the frequency corresponding to position k, and

w is the absolute window position expressed in time units of the associated window.

14. A method of fast Fourier transform (FFT) analysis window displacement compensation in a COFDM modulator, comprising:

receiving a radio-transmitted signal in a window corresponding to one symbol, the symbol carrying a plurality of phase and amplitude modulated carriers, one or more of the carriers are shifted in frequency from one symbol to the next symbol to form pilots, and extracting these symbols and converting these symbols into digital signals;

receiving the digital signals and determining and readjusting the position of the windows;

receiving the windows and performing a fast Fourier transform with the windows and outputting a transformed signal that includes complex coefficients;

receiving a position signal and outputting a conversion signal that is corrected for distortion;

receiving the transformed signal and the conversion signal and providing an interpolated signal; and

receiving the interpolated signal and outputting a corrected coefficient signal.

15. The method of claim 14, further comprising receiving the transformed signal and outputting a delayed transformed signal.

16. The method of claim 14, further comprising generating a phase-locked loop signal synchronized on a correlation signal obtained by a correlation product between the received signal and this same signal delayed by one symbol, each symbol being preceded by a guard interval corresponding to a copy of the end of the symbol.

17. The method of claim 14, comprising calculating distortion according to the following:

$$d_{n,k} = \left(1 - \frac{s}{4}\right) A_{n-s,k} e^{j2\pi f_k (w_{n-s} - w_n)} + \frac{s}{4} A_{n+4-s,k} e^{j2\pi f_k (w_{n+4-s} - w_n)}$$

where

A is the received anchors,

S is equal to (n modulo 4 - k/3 modulo 4) modulo 4,

n is the symbol number,

k is the window position,

f_k is the frequency corresponding to position k, and

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JC01 Rec'd PCT/PTO 19 DEC 2000

COFDM DEMODULATOR WITH FFT ANALYSIS WINDOW DISPLACEMENT COMPENSATION

The present invention relates to a COFDM ("Coded Orthogonal Frequency Division Multiplex") demodulator, and more specifically to such a demodulator used for radio transmissions.

Fig. 1 is intended for illustrating the principle of a COFDM modulation. Data packets to be transmitted are put in the form of N complex coefficients associated with N respective frequencies. The number N of frequencies is a power of 2, equal, for example, to 8192 (digital television diffusion). Each complex coefficient corresponds to a vector that is illustrated in Fig. 1 as starting from a frequency axis at a point indicating the frequency associated with the coefficient.

The N coefficients are processed by inverse fast Fourier transform (IFFT), which generates a "symbol" formed of a sum of modulated carriers, each carrier having the amplitude and the phase determined by the associated complex coefficient. The symbol thus generated is transmitted and a receiver submits it to the inverse processing, that is, a fast Fourier transform (FFT) to restore the initial complex coefficients.

As shown in Fig. 1, some regularly distributed vectors P1, P2, P3 ... have a known constant value. These vectors, or the corresponding carriers, are called the pilot carriers. They are used to reflect the distortions undergone by the transmitted

signal and to interpolate the corrections to be performed on the unknown vectors located between the pilots.

Fig. 2 illustrates a transmission of several successive symbols Sn-1, Sn... As shown, each of these symbols is preceded by a guard interval G that is a copy of a portion of the end of the corresponding symbol. The guard intervals are used to avoid inter-symbol modulation distortions caused by an echo of the transmission at the receive level. Fig. 2 also shows an echo SEn-1, GEn-1... of the transmitted signal. This echo is delayed with respect to the main signal by a duration shorter than that of a guard interval G.

Each symbol S is normally analyzed by the FFT circuit of the receiver in a window W of same length as the symbol. If there were no guard interval, an analysis window W coinciding with a symbol of the main signal would straddle two symbols of the echo signal. This would result in an error difficult to correct in the FFT.

Guard interval G, provided that it is greater than the echo delay, provides an adjustment margin of analysis window W so that it only coincides with portions belonging to the same symbol, in the main signal as well as in the echo. The fact that an analysis window straddles a symbol and its guard interval only results in a phase-shift that is corrected, in particular, by means of the above-mentioned pilot carriers.

Fig. 3 illustrates a method used in a conventional COFDM demodulator, such as described in French patent 2,743,967 to find the symbol beginnings, at the beginning of a reception, this to adjust analysis window W. A correlation product between the received signal and this same signal delayed by one symbol is performed. This enables detecting the time when each guard interval of the delayed signal coincides with an identical portion of the received signal, that is, the end of the corresponding symbol in the received signal.

Correlation product C, initially zero, starts progressively increasing from the beginning of each guard interval of the delayed signal. The maximum value is reached at the end of the guard interval, after which correlation product C starts

decreasing to reach value zero. In the presence of an echo signal, the correlation peaks are lower and shift in the echo direction, so that they quite well show where the analysis windows are to start.

However, signals are most often noise-infested and it is difficult to determine the position of the correlation peaks with sufficient precision. For this purpose, the circuit described in the above-mentioned French patent enables refining the position, upon circuit setting, by analyzing the pulse response of the channel. Of course, the received signal may undergo frequency or phase drifts in operation, whereby the position of the windows must be regularly revised as will be described hereafter.

Fig. 4 very schematically shows the architecture of a COFDM demodulator such as described in the above-mentioned French patent. It is a system for receiving radio-transmitted digital television signals. In a radio transmission, the symbols are carried by a carrier of high frequency, which frequency is lowered by a tuner not shown. An element 10 of the architecture of Fig. 4 extracts the symbols from this carrier and converts them into digital. An element 12 determines the position of the analysis windows, as described in relation with Fig. 3, and readjusts, if necessary, the position of the analysis windows. The FFT is performed at 14 with the windows determined at 12. The coefficients provided by the FFT are put to wait at 16 to interpolate at 18 the distortions undergone by the coefficients. The distortions, which are complex numbers, are used to correct the coefficients at 20.

The pulse response of the channel is calculated at 22 based on the distorted pilots such as received. This pulse response enables determining whether the analysis window position is correct or whether it must be modified. The optimal window position is obtained when the power of the pulse response is maximum.

As indicated previously, each symbol includes pilots of known identical characteristics (they generally have a unity amplitude and a null or 180° phase, according to a law known by

the receiver). The pilots such as received by the demodulator reflect the distortions undergone by the pilots. The value of the distortion is $A_p = P_p/E_p$, where P_p is the value of the received pilot of position p and E_p is the value of the corresponding transmitted pilot. A distortion A_p is currently called an "anchor". These anchors are used to calculate by interpolation the distortions, noted d_k hereafter ($k \neq p$), at the positions k having no pilot.

The error correction at 20 consists of calculating the ratio of the coefficients such as received and of the respective interpolated distortions : $D_k = R_k/d_k$, where D_k is the corrected value and R_k is the received value.

Given that the pilots do not carry data, their number is desired to be limited. However, the smaller the number of pilots, the more interpolation errors between two consecutive pilots are made. To improve this situation, the pilots are shifted by several positions from one symbol to the next one and a bidimensional interpolation is performed on several consecutive symbols. In the example described hereafter, each symbol includes one pilot every twelve positions and the pilots are shifted by three positions from one symbol to the next one.

Fig. 5 illustrates this bidimensional interpolation. It shows an array, the rows of which correspond to consecutive symbols, the last received symbol being at the last row. The array columns correspond to the successive symbol carrier positions or frequencies. Hatched squares correspond to the received anchors. Due to the shifting of the pilots from one symbol to the next one, close anchors appear in some columns (every three columns in the present example).

All the distortions are first interpolated in the columns containing the anchors. Then, a finite impulse response filter 24 interpolates the missing distortions of each row.

With the above-mentioned example, the distortions of a symbol n-3 can be interpolated at the time when symbol n is received. Further, the interpolation of some distortions of symbol n-3 will require anchors of prior symbols, back to symbol

n-6. This method thus requires completely storing symbols n-1 to n-3 and also storing the anchors only of symbols n-4 to n-6.

An interpolated distortion of position k in a symbol n expresses as:

$$d_{n,k} = (1 - \frac{s}{4})A_{n-s,k} + \frac{s}{4}A_{n+4-s,k} \quad (1)$$

where terms A are the received anchors and

where s = (n modulo 4 - k/3 modulo 4) modulo 4.

As an example, with this expression, the interpolated distortion in third position of symbol n-3 in Fig. 5 is expressed as ¾ A_{n-4} + ¼ A_n.

Fig. 6 schematically shows a distortion interpolation circuit 18 implementing the method of Fig. 5. Delay circuit 16 of Fig. 4 stores three consecutive symbols Sn-1, Sn-2, Sn-3 in a shift register. The received anchors A_{n-1} to A_{n-6} of six consecutive symbols necessary to interpolate the distortions in the columns are stored in six cascade-connected shift registers 26. Register 16 and the first register 26 receive current symbol Sn. A four-input multiplexer 28 receives on a first input the anchors of symbol Sn, multiplied by one quarter; on a second input, the anchors A_{n-1} provided by the first register 26, multiplied by one half; on a third input, the anchors A_{n-2} provided by the second register 26, multiplied by three quarters; and on its fourth and last input, the anchors A_{n-3} provided by the third register 26.

A multiplexer 30 receives on a first input anchors A_{n-4} provided by the fourth register 26, multiplied by three quarters; on a second input, anchors A_{n-5} provided by the fifth register 26, multiplied by one half; on a third input, anchors A_{n-6} provided by the sixth register 26, multiplied by one quarter; and on its last input, value 0. At 32, the sum of the outputs of multiplexers 28 and 30 is provided to filter 24. Multiplexers 28 and 30 are controlled by a same selection signal SEL that selects the adequate input of the multiplexers according to position k of the distortion to be interpolated.

As indicated previously, the position of the FFT analysis window is determined once and for all in a setting phase. It is however provided to regularly check that the window position

is good and to readjust this position if necessary. However, when the position of the analysis window is modified, the phase of each of the symbol carriers is correlatively modified, and this phase modification appears as a distortion that must be corrected. If the phase modification occurs for a current symbol n, the anchors of this current symbol will not have the same phase reference as the anchors of the preceding symbols, whereby it will be impossible to interpolate the distortions involving the anchors of symbol n.

Fig. 7 is intended for illustrating this phenomenon in further detail. This drawing shows a phase variation of an anchor of same position in consecutive symbols numbered from zero, this in the context of the example of Fig. 5 where an anchor is found at the same position every four symbols.

It is assumed that the received symbols regularly take advance on the fixed analysis window, which results in an increase of the anchor phase, as shown for symbols 0, 4, and 8, 12. The interpolated phases are marked with circles located on straight lines connecting the phase values of the anchors.

At the seventh symbol, the analysis window is advanced by an interval τ to catch up on the symbol phase advance. As a result, the phase should evolve as indicated by squares, that is, continuing to regularly increase for symbols 5 and 6, abruptly dropping for symbol 7, and regularly increasing again. The phase drop is sensible for the first time in the anchor of symbol 8, and the errors interpolated for symbols 5 to 7, being located on the straight line connecting the phase values of the anchors of symbols 4 and 8, are erroneous. As a result, symbols 5 to 7 are lost, which loss is most often perceptible, especially on a television screen in the case where the symbols correspond to video signals.

When the receiver and the transmitter are at fixed positions, as it is in most cases, an analysis window readjustment seldom occurs and such signal disturbances may be acceptable.

However, it may be envisaged to use a receiver in a moving vehicle, such as a train, in which case the window

readjustments should be frequent, making unacceptable the disturbances that this would cause.

An object of the present invention is to provide a COFDM demodulator that enables suppressing any disturbance due to a readjustment of the analysis window.

To achieve this object, the present invention provides a COFDM demodulator including a fast Fourier transform circuit analyzing a received signal in a window corresponding to one symbol, each symbol carrying several phase and amplitude modulated carriers, some of which, shifted in frequency in a predetermined way from one symbol to the next one, form pilots; a bidimensional filter for interpolating, from anchors corresponding to the pilots such as received from several consecutive symbols, the distortion undergone by each carrier; and means for correcting the window shifting with respect to an optimal position. The demodulator includes means for correcting each distortion according to window shifting corrections performed respectively for the symbol associated with the distortion and for the symbols associated with the anchors used to interpolate the distortion.

According to an embodiment of the present invention, the means for correcting the window shifting include a phase-locked loop synchronized on a correlation signal obtained by a correlation product between the received signal and this same signal delayed by one symbol, each symbol being preceded by a guard interval corresponding to a copy of the end of the symbol.

According to an embodiment of the present invention, each distortion is, in frequency after Fourier transform, a weighted sum of two anchors of the same position in a preceding symbol and in a following symbol, to which anchors have been added respective phases corresponding to the shiftings undergone by the analysis window for the preceding and following symbols, and to which anchors has been subtracted a phase corresponding to the shifting undergone by the analysis window for the symbol associated with the distortion.

The foregoing objects, features and advantages of the present invention will be discussed in detail in the following

non-limiting description of specific embodiments in connection with the accompanying drawings.

Fig. 1, previously described, illustrates phase and amplitude modulated carriers in a COFDM transmission system;

Fig. 2, previously described, shows signals received by a COFDM demodulator and windows of FFT analysis of the signals;

Fig. 3, previously described, illustrates a symbol beginning detection method in a conventional COFDM demodulator;

Fig. 4, previously described, schematically shows an architecture of a conventional COFDM demodulator;

Fig. 5, previously described, illustrates a bidimensional distortion interpolation method;

Fig. 6, previously described, schematically shows a circuit enabling implementation of the interpolation of Fig. 5;

Fig. 7, previously described, illustrates a problem linked to an FFT analysis window readjustment in a conventional demodulator;

Fig. 8 schematically shows an architecture of a COFDM demodulator according to the present invention; and

Fig. 9 shows in further detail an element of the demodulator of Fig. 8.

To avoid interpolation errors caused by a bidimensional interpolation method when the position of an FFT analysis window is modified with respect to the received signal, the present invention provides involving in the interpolation calculations the phase shift caused, for each frequency, by the position modification of the analysis window.

In the conventional example of Figs. 5 and 6, an interpolated distortion $d_{n,k}$ is expressed as:

$$d_{n,k} = (1-\frac{s}{4})A_{n-s,k} + \frac{s}{4}A_{n+4-s,k} \qquad (1)$$

where terms A are the received anchors and

s = (n modulo 4 - k/3 modulo 4) modulo 4.

According to the present invention, distortion $d_{n,k}$ is calculated according to the following relation:

$$d_{n,k} = (1-\frac{s}{4})A_{n-s,k}e^{j2\pi f_k(w_{n-s}-w_n)} + \frac{s}{4}A_{n+4-s,k}e^{j2\pi f_k(w_{n+4-s}-w_n)}$$

where f_k is the frequency corresponding to position k and where each term w corresponds to the absolute position expressed in time units of the analysis window that has been used for the symbol indicated by the index of term w.

Applying this relation amounts to applying conventional relation (1), having previously added to the two received anchors A respective phases corresponding to the shiftings undergone by the analysis window for the symbols associated with the two anchors, and subtracted to the value so obtained the phase corresponding to the shifting undergone by the analysis window for the symbol associated with the interpolated distortion.

If this relation is applied as an example to the interpolation for symbol 6 of Fig. 7, $w_{n-s} = w_4 = 0$, $w_n = w_6 = 0$ and $w_{n-s+4} = w_8 = \tau$. In other words, the anchor of symbol 4 is not modified while the anchor of symbol 8 is increased by τ, which brings this anchor back in alignment with the received interpolated anchors of symbols 0 to 4 and enables correctly interpolating the anchor for symbol 6, indicated by a square.

As just shown in this example, the present invention can be used in a demodulator of the type in Fig. 4 where the position of the analysis window is conventionally determined at the beginning and readjusted from time to time, as described in relation with Fig. 3.

However, this conventional method of adjusting the analysis window is complex and has up to now required the use of a DSP (digital signal processor). This method has been used because it was important to obtain a precise window position from the beginning, to suppress any need for subsequent adjustment, or at least to postpone as far as possible the subsequent adjustment.

Conversely, according to the present invention, since each anchor is corrected according to the current position of the analysis window, the analysis window may be permanently moving. Thus, it can be envisaged to adjust the position of the analysis window by means of a phase-locked loop (PLL) synchronized on correlation signal C described in relation with Fig. 3.

Fig. 8 shows an architecture of a COFDM demodulator using this method. This architecture is similar to that of Fig. 4, and the same elements are designated with the same reference numbers. Distortion interpolation circuit 18 of Fig. 4 is here replaced with a distortion interpolation circuit 18' according to the present invention. Circuit 12 for setting the window position is permanently controlled by a PLL 40 that synchronizes on correlation signal C described in relation with Fig. 3. Preferably, the PLL is digital; it then includes an accumulator that indicates the absolute position of the analysis window with respect to the corresponding symbol, which position can be directly exploited as a value w. The consecutive values w are converted at 42 to be usable by distortion interpolation circuit 18'.

Fig. 9 shows in further detail interpolation circuit 18' and conversion circuit 42. Circuit 18' is similar to that of Fig. 6, and the same references designate the same elements. Circuit 18' differs from circuit 18 in that a complex number multiplier 44 has been inserted at the output of each of multiplexers 28 and 30.

Circuit 42 includes six cascade shift registers 46, a first one of which receives, for each symbol, an analysis window shift value w. Thus, registers 46 store values w for six consecutive symbols and this in concordance with anchors A stored in shift registers 26. A multiplexer 48 respectively receives on four inputs the inputs of the first to fourth registers 46. A multiplexer 50 receives on the three first inputs the respective outputs of the last three registers 46, and on a fourth input value zero. Multiplexers 48 and 50 are controlled by the same selection signal SEL as multiplexers 28 and 30.

Each of multiplexers 48 and 50 is followed by a subtractor 52 that subtracts to the output of the respective multiplexer the output of the third register 46. The outputs of subtractors 52 are provided in the form of complex numbers to the respective multipliers 44 after having been multiplied by $2\pi f_k$ at 54 and having undergone a polar-to-cartesian conversion at 56.

When the last input of the multiplexers is selected, the value provided by interpolation circuit 18' is a received anchor that must not be corrected. In this case, subtractor 52 associated with multiplexer 48 provides a zero value corresponding to complex value 1 that does not modify the received anchor provided by multiplexer 28. This received anchor is not modified either by adder 32, which receives a zero value from multiplier 44 associated with multiplexer 30.

A conventional COFDM demodulator generally includes a multiplier by a complex number of the type $e^{j2\pi f_k T}$ at the output of the FFT circuit, where T is half the duration of guard intervals G. Indeed, it is assumed that the analysis windows normally start at the centers of the guard intervals rather than at the beginnings of the symbols, and this multiplication compensates for the resulting shift. This multiplier may advantageously be used in shared time to perform the multiplications required by the present invention.

CLAIMS

1. A COFDM demodulator including:

a fast Fourier transform circuit (14) analyzing a received signal in a window corresponding to one symbol, each symbol carrying several phase and amplitude modulated carriers, some of which (P), shifted in frequency in a predetermined way from one symbol to the next one, form pilots;

a bidimensional filter (18) for interpolating, from anchors (A) corresponding to the pilots such as received from several consecutive symbols (S), the distortion undergone by each carrier; and

means (12) for correcting the window shifting with respect to an optimal position;

characterized in that it comprises means (42) for correcting each distortion according to window shifting corrections performed respectively for the symbol associated with the distortion and for the symbols associated with the anchors used to interpolate the distortion.

2. The demodulator of claim 1, characterized in that the means for correcting the window shifting include a phase-locked loop (40) synchronized on a correlation signal (C) obtained by a correlation product between the received signal and this same signal delayed by one symbol, each symbol being preceded by a guard interval (G) corresponding to a copy of the end of the symbol.

3. The demodulator of claim 1, characterized in that each distortion is, in the frequency field after Fourier transform, a weighted sum of two anchors of same position in a preceding symbol and in a following symbol, to which anchors have been added respective phases corresponding to the shiftings undergone by the analysis window for the preceding and following symbols, and to which anchors has been subtracted a phase corresponding to the shifting undergone by the analysis window for the symbol associated with the distortion.

COFDM DEMODULATOR WITH FFT ANALYSIS WINDOW DISPLACEMENT COMPENSATION

Abstract

A COFDM demodulator including a fast Fourier (14) transform circuit analyzing a received signal in a window corresponding to one symbol, each symbol carrying several phase and amplitude modulated carriers, some of which (P), shifted in frequency in a predetermined way from one symbol to the next one, form pilots; a bidimensional filter (18) for interpolating, from anchors (A) corresponding to the pilots such as received from several consecutive symbols (S), the distortion undergone by each carrier; and means (12) for correcting the shifting of the window with respect to an optimal position. The demodulator includes means (42) for correcting each distortion according to window shifting corrections performed respectively for the symbol associated with the distortion and for the symbols associated with the anchors used to interpolate the distortion.

Figure 8.

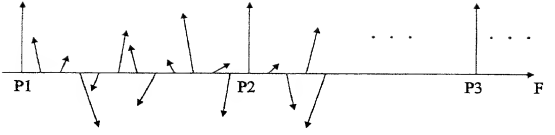


Fig 1

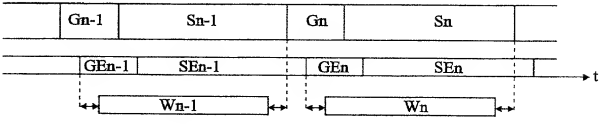


Fig 2

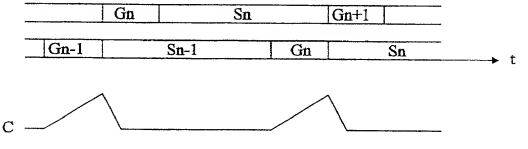


Fig 3

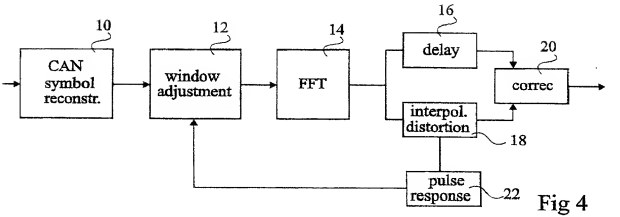


Fig 4

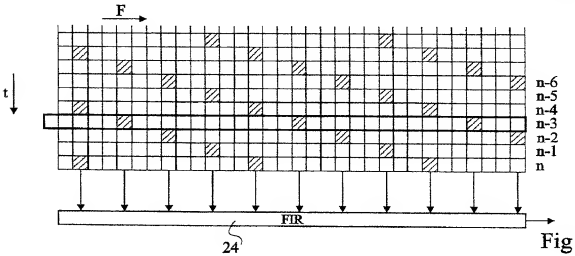


Fig 5

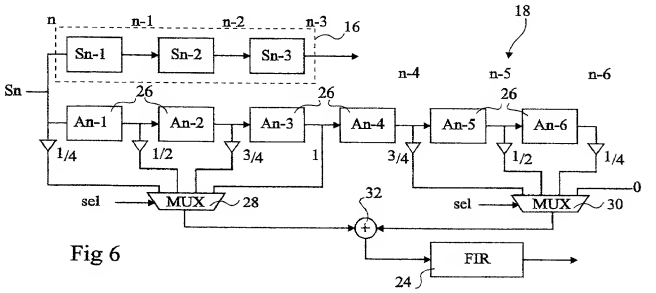


Fig 6

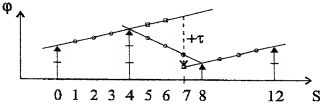


Fig 7

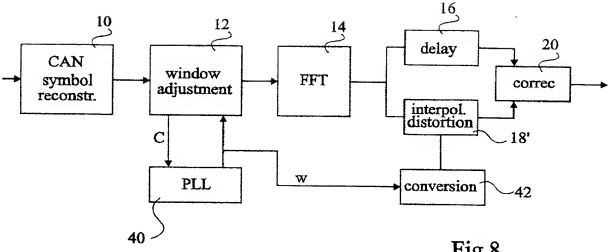
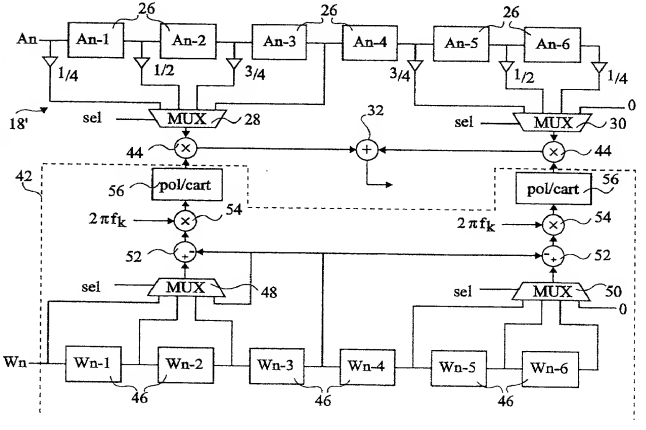

10
CAN symbol reconstr.
12
window adjustment
14
FFT
16
delay
20
correc
interpol. distortion
18'
C
PLL
w
conversion
42
40

Fig 8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An-6
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Wn
Wn-1
Wn-2
Wn-3
Wn-4
Wn-5
Wn-6
46

Fig 9

Declaration and Power of Attorney for Patent Application
Déclaration et Pouvoirs pour Demande de Brevet
French Language Declaration

En tant que l'inventeur nommé ci-après, je déclare par le présent acte que:

As a below named inventor, I hereby declare that:

Mon domicile, mon adresse postale et ma nationalité sont ceux figurant ci-dessous à côté de mon nom.

My residence, post office address and citizenship are as stated below next to my name.

Je crois être le premier inventeur original et unique (si un seul nom est mentionné ce-dessous), ou l'un des premiers co-inventeurs originaux (si plusieurs noms sont mentionnés ci-dessous) du sujet revendiqué, pour lequel une demande de brevet a été déposée concernant l'invention intitulée:

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

COFDM DEMODULATOR WITH FFT ANALYSIS WINDOW DISPLACEMENT COMPENSATION

et dont les caractéristiques sont fournies ci-joint à moins que la case suivante n'ait été cochée:

the specification of which is attached hereto unless the following box is checked:

☒ a été déposée le _____
sous le numéro de Demande des Etats-Unis ou le Numéro de demande international PCT
_____ et modifiée le
_____ (le cas échéant).

☐ was filed on _____
as United States Application Number or PCT International Application Number ___ and was amended on _____ (if applicable).

Je déclare par le présent acte avoir passé en revue et pris connaissance du contenu des caractéristiques ci-dessus, revendications comprises, telles que modifiées par tout amendement dont il aura été fait référence ci-dessus.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

Je reconnais devoir divulguer toute information pertinente à l'examen de cette demande, comme le définit le Titre 37, § 1.56 du Code fédéral des réglementations.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, §1.56.

Form PTO-FB-260 (8-83)
F:\wsgs\sgs4-12 (10-99)
Patent and Trademark Office-U.S. DEPARTMENT OF COMMERCE

French Language Declaration

Je revendique par le présent acte avoir la priorité étrangère, en vertu du Titre 35, § 119 du Code des Etats-Unis, sur toute demande étrangère de brevet ou certificat d'inventeur figurant ci-dessous et ai aussi pris connaissance de toute demande étrangère de brevet ou de tout certificat d'inventeur ayant une date de dépôt précédant celle de la demande à propos de laquelle une priorité est revendiquée.

I hereby claim foreign priority under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed.

Prior foreign applications
Demande(s) de brevet antérieure(s)

(Number) (Numéro)	(Country) (Pays)	(Day/Month/Year Filed) (Jour/Mois/Année de dépôt)	Priority claimed Droit de priorité revendiqué Yes Oui	No Non
PCT/FR00/00477	PCT	25 FEBRUARY 2000	☑	☐
99/02653	FRANCE	26 FEBRUARY 1999	☑	☐
			☐	☐

Je revendique par le présent acte tout bénéfice, en vertu du Titre 35, § 120 du Code des Etat-Unis, de toute demande de brevet effectuée aux Etats-Unis figurant ci-dessous et, dans la mesure où le sujet de chacune des revendications de cette demande de brevet n'est pas divulgué dans la demande américaine préalable, en vertu des dispositions du premier paragraphe du Titre 35, § 112 du Code des Etats-Unis, je reconnais devoir divulguer toute information pertinente à la demande de brevet comme défini dans le Titre 37, § 1.56 du Code fédéral des réglementations, dont j'ai pu disposer entre la date de dépôt de la première demande et la date de dépôt de la demande nationale ou PCT internationale:

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, §1.56, which became available between the filing data of the prior application and the national or PCT international filing date of this application:

(Application Serial No.) (No. de série de la demande)	(Filing Date) (Date de dépôt)	(Statut) (breveté, en attente, annulé)	(Status) (patented, pending, abandoned)
(Application Serial No.) (No. de série de la demande)	(Filing Date) (Date de dépôt)	(Statut) (breveté, en attente, annulé)	(Status) (patented, pending, abandoned)

Je déclare par le présent acte que toute déclaration ci-incluse est, à ma connaissance, véridique et que toute déclaration formulée à partir de renseignements ou de suppositions est tenue pour véridique; et de plus, que toutes ces déclarations ont été formulées en sachant que toute fausse déclaration volontaire ou son équivalent est passible d'une amende ou d'une incarcération, ou des deux, en vertu de la Section 1001 du Titre 18 du Code des Etats-Unis et que de telles déclarations volontairement fausses risquent de compromettre la validité de la demande de brevet ou du brevet délivré à partir de celle-ci.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

French Language Declaration

POUVOIRS: En tant que l'inventeur cité, je désigne par la présente l'(les) avocat(s) et/ou agent(s) suivant(s) pour qu'il(s) poursuive(nt) la procédure de cette demande de brevet et traite(nt) toute affaire avec le Bureau des brevets et marques s'y rapportant. *(mentionner le nom et le numéro d'enregistrement)*

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith (*list name and registration number*)

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Signature de l'inventeur Date 22 Sept 2000	Inventor's signature Date
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Nom complet du second co-inventeur, le cas échéant	Full name of second joint inventor, if any
Signature du second inventeur Date	Second Inventor's signature Date
Domicile	Residence
Nationalité	Citizenship
Adresse postale	Post Office Address

(Fournir les mèmes renseignements et la signature de tout co-inventeur supplémentaire.)

(Supply similar information and signature for third and subsequent joint inventors.)